2016

Sow lying behaviors before, during and after farrowing

F. Lao
China Agricultural University

T. M. Brown-Brandl
United States Department of Agriculture

Iowa Select Farms

G. Teng
China Agricultural University

Kai Liu
Iowa State University, kail@iastate.edu

See next page for additional authors

Sow lying behaviors before, during and after farrowing

Abstract
Piglet pre-weaning mortality remains a considerable challenge for the swine industry, representing one of the key areas where animal well-being and economical interest coincide. Sows and piglets carry out a complex series of behaviors during the farrowing/lactation period. These behaviors during the first few days after parturition are extremely important for piglet survival, and they can be greatly impacted by the farrowing system, environment, and/or management. The risk of sow crushing is much greater for piglets when the sow changes her postures. Limited studies have investigated the effects of environment on sow's posture changes or basic understanding of sow's lying or other behavior patterns. Using a computer vision and analysis system, this study aims to characterize sows' postural behaviors before, during and after farrowing to ultimately reduce pre-weaning piglet mortality and to understand the relationship between placement of localized heat source (heat lamp) and its impact on sows' lying preference, if any. Analysis of data with 15 sows thus far reveals the following preliminary observations. The sows do not seem to have a preference of lying on one side vs. the other before farrowing regardless of absence or presence of a heat lamp on the side. However, heat lamp in the creep area significantly affects the sows' lying side in the first 3 days after farrowing. Interestingly, the lactating sows demonstrated the postural behavior of facing more of her backside toward the heat lamp relative to before farrowing. Such a behavior would not be in the best interest of the piglets' well-being. The presence of heat lamp during the lactation period seemed to have some carryover effect on the sow's lying posture when the heat lamp was tuned off with elder piglets. Sows change their behaviors (lying, sitting, standing, and movement) over the farrowing cycle. In particular, sow's behaviors change sharply 24 h prior to farrowing, making it is possible to predict farrowing time by analyzing the behavioral changes with the automatic tracking system. More data are being collected.

Keywords
Pre-weaning mortality, sow postural behaviors, image analysis, localized heating

Disciplines
Agriculture | Animal Sciences | Bioresource and Agricultural Engineering | Meat Science

Comments
This presentation is published as Fengdan, L. A. O., Tami M. Brown-Brandl, John P. Stinn, Guanghui Teng, Kai Liu, and Hongwei Xin. "Sow lying behaviors before, during and after farrowing." In 2016 ASABE Annual International Meeting, p. 1. American Society of Agricultural and Biological Engineers, 2016. doi: 10.13031/aim.20162461921. Posted with permission.

Authors
F. Lao, T. M. Brown-Brandl, Iowa Select Farms, G. Teng, Kai Liu, and Hongwei Xin

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation
DOI: 10.13031/aim.20162461921
Paper Number: 162461921

Sow lying behaviors before, during and after farrowing

F. Lao[1,5], T.M. Brown-Brandl[2], J.P. Stinn[3], G. Teng[4], K. Liu[5], H. Xin[5,*]

[1]Network Center, China Agricultural University, Beijing, China

[2]USDA-ARS Meat Animal Research Center, Clay Center, NE, USA

[3]Iowa Select Farms, Iowa Falls, IA, USA

[4]College of Water Resources & Civil Engineering, China Agricultural University, Beijing, China

[5]Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, USA

* Corresponding author: hxin@iastate.edu

Written for presentation at the
2016 ASABE Annual International Meeting
Sponsored by ASABE
Orlando, Florida
July 17-20, 2016

Abstract. *Piglet pre-weaning mortality remains a considerable challenge for the swine industry, representing one of the key areas where animal well-being and economical interest coincide. Sows and piglets carry out a complex series of behaviors during the farrowing/lactation period. These behaviors during the first few days after parturition are extremely important for piglet survival, and they can be greatly impacted by the farrowing system, environment, and/or management. The risk of sow crushing is much greater for piglets when the sow changes her postures. Limited studies have investigated the effects of environment on sow's posture changes or basic understanding of sow's lying or other behavior patterns. Using a computer vision and analysis system, this study aims to characterize sows' postural behaviors before, during and after farrowing to ultimately reduce pre-weaning piglet mortality and to understand the relationship between placement of localized heat source (heat lamp) and its impact on sows' lying preference, if any. Analysis of data with 15 sows thus far reveals the following preliminary observations. The sows do not seem to have a preference of lying on one side vs. the other before farrowing regardless of absence or presence of a heat lamp on the side. However, heat lamp in the creep area significantly affects the sows' lying side in the first 3 days after farrowing. Interestingly, the lactating sows demonstrated the postural behavior of facing more of her backside toward the heat lamp relative to before farrowing. Such a behavior would not be in the best interest of the piglets' well-being. The presence of heat lamp during the lactation period seemed to have some carryover effect on the sow's lying posture when the heat lamp was tuned off with elder piglets. Sows change their behaviors (lying, sitting, standing, and movement) over the farrowing cycle. In particular, sow's behaviors change sharply 24 h prior to farrowing, making it is possible to predict farrowing time by analyzing the behavioral changes with the automatic tracking system. More data are being collected.*

Keywords. *Pre-weaning mortality, sow postural behaviors, image analysis, localized heating*

1. Introduction

Piglet pre-weaning mortality has been and continues to be a considerable challenge for the swine industry, representing one of the key areas where animal well-being and economical interest coincide (Xin et al., 1997; Baxter et al., 2010). Sows and piglets carry out a complex series of behaviors during the farrowing/lactation period. In the first few days after parturition, the behaviors of sows and piglets are extremely important for piglet survival and it can be greatly impacted by the farrowing system, environment, and management. Researchers have found that the risk of crushing is much greater for piglets when the sow changes her positon or behaviors, especially from lying to standing and vice versa. Also, pen-housed sows have been reported to crush a large number of piglets while changing lying positions (Alonso et al., 2007; Shankar et al., 2009). The piglets need to stay close to the sow or a heat source to avoid hypothermia. Yet exposure of the sow or part of her body to heat can decrease her feed intake and induce changes in her postural behaviors. Studies are limited that investigate the effects of the micro-environment in farrowing facilities on postural behaviors of sows and basic understanding of sow's lying or other behavior patterns as affected by the placement of creep heat source.

Many sensors and sensing techniques are available or under development, which has enhanced the ability of automating measurements of pig's behavioral and biological responses. For instance, to improve the ability of attending farrowing and piglet livability, Cornou and Kristensen (2014) researched a method to monitor sow's activity before, during and after farrowing using accelerometer measurements. By means of image processing, Viazzi et al. (2014) developed continuous automated detection of aggressive interactions among pigs and achieved an 89% detection accuracy. Applying a multi-process Kalman filter, Cornou and Lundbye-Christensen (2010) reported a 64% average recognition rate for passive (lying laterally or sternally) and active (feeding, rooting, and walking) behaviors of sows. Escalante et al. (2013) employed a supervised machine learning approach to classify sow activities recorded with accelerometers and achieved an average recognition rate of 74.6%. Oczak et al. (2015) used accelerometer data to classify nest-building behaviors of non-crated farrowing sows and obtained 86% accuracy. Recently, depth image analysis has been used as a new method of quantifying the animal's dynamic behaviors in both horizontal and vertical dimensions (Gregersen et al., 2013; Van Hertem et al., 2013; Viazzi et al., 2013; Lao et al., 2016). The depth image technique is superior to the traditional digital imaging method in that it is immune to changes in the light conditions of the environment.

Localized heating, in the form of heat lamp or heat mat, is typically used in farrowing crates to accommodate the thermal needs of the piglets, as a much lower room temperature is maintained for the sow's thermal comfort (Xin et al., 1997; Zhou and Xin, 1999; Zhang and Xin, 2000; Zhang and Xin, 2001; Zhang and Xin, 2005). A critical question that remains to be addressed is how the placement of the localized heat source affects the sow's postural behaviors. This behavioral response can potentially have significant implications for the well-being and production performance of both the sows and the piglets. Our hypothesis is that location of the creep heat source will impact the lying pattern of the sow, with more time spent on her udder side facing the heat source to accommodate suckling of the piglets.

Therefore, the main objective of the study was to test the afore-stated hypothesis through quantifying sow's dynamic and postural behaviors (lying, sitting, standing, kneeling, and moving) before, during and after farrowing with the absence and presence of the creep heat source (heat lamp). The system for depth image acquisition and computerized analysis of the sow's behaviors was previously developed and described (Lao et al., 2016).

2. Material and Methods

2.1 Animals and data collection

Fifteen farrowing crates were randomly selected at the swine research facility of the USDA-ARS Meat Animal Research Center, Clay Center, Nebraska, USA. The farrowing crates each housed one Landrace sow and the monitoring period covered the entire farrowing/lactation period in most cases. The farrowing crate each had the dimension of 1.5 m W × 2.1 m L with 0.6 m wide sow area and a 0.45 m wide piglets creep area on each side of the sow. Room temperature was kept at 22 - 25ºC. One heat lamp (HL, 175 W) was suspended above the creep area on the sow's left side in 13 crates and on the sow's right side in the remaining 2 crates.

The experiment was carried out during the period of January 13 to November 30, 2015. Images were collected for approximately 320 monitoring days (Table 1), with most days covering 24 hr. A top-view 3D Kinect camera for Windows v1 (Microsoft Corp., USA) was used to monitor the farrowing crate (Figure 1). The camera was installed 2.20 m above the crate floor and captured digital images in JPEG format (used for manual verification) and depth images in text format (used for automatic recognition and manual verification). Both types of images had a resolution of 640×480 pixels. The Kinect camera was connected via a USB port to a computer that used a 2 TB usb3.0 moveable hard disk to store the digital and depth images for subsequent analysis. The images were recorded at approximately 6 s intervals and thus needed a huge storage space. The image data acquisition system generally worked well except for the following circumstances. First, automatic rebooting of the computer system after an automatic update of the operating system did not restart the data collection system. Disabling the automatic update feature solved the problem. Second, the loss of data occurred with the delayed replacement of the 2 TB portable storage hard disk upon reaching its capacity. Finally, some difficulty was encountered in capturing all the desired pre- and post-farrowing days for all the sows monitored.

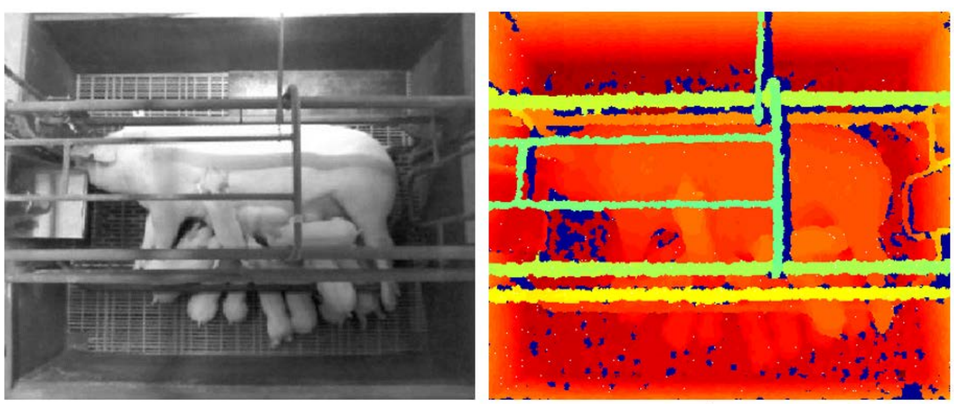
The depth images were processed to extract the following sow's behaviors: lying, sitting, standing, kneeling, feeding, drinking, transitioning or shifting from one behavior to another, and moving. This paper focuses on the delineation of the sows lying postures before, during and after farrowing.

The monitoring period was partitioned into several phases to delineate the sow's behaviors during different stages of the farrowing cycle, namely, before farrowing without heat lamp or HL (P1: BF-HL), before farrowing with HL (P2: BF+HL), after farrowing with HL (P3: AF+HL), and after farrowing without HL (P4: AF-HL). Since P3 (AF+HL) is a longer and more critical time period, it was further divided into sub-periods: the first 3 days after farrowing with HL (P3-1: AF+HL_F3d), the first 6 days after farrowing with HL (P3-2: AF+HL_F6d), the last 3 days after farrowing with HL (P3-3: AF+HL_L3d), and all the time after farrowing with HL (P3: AF+HL).

When lying down and nursing, the sow would be either on her left side (LS) or right (RS). Either the backside or the udders side would be toward the heat lamp, designated as BTH or UTH. When the heat lamp is placed on the left side of the sow (13 of the 15 crates), RS lying means UTH while LS lying means BTH. When the heat lamp is placed on the right side of the sow (2 of the 15 crates), the opposite is true.

Table 1. Monitoring day information of sow's behaviors before and after farrowing

Sow #	Monitoring period	Monitoring days (w.r.t farrowing day)	Heat lamp position	Farrowing date	Missing days
1	Jan 13-Feb 10	25 (-8 to +21)	left	Jan 21	Jan 15, Jan 17-Jan 19
2	Jan 22-Feb 10	20 (+4 to +18)	left	Jan 18	Jan 18-Jan 21
3	Jan 24-Feb 10	18 (+4 to +21)	left	Jan 21	Jan 21-Jan 23
4	Jun 29-Jul 11	13 (-4 to +9)	left	Jul 03	
5	Jun 29-Jul 21	17 (-7 to +16)	left	Jul 06	Jul 03-Jul 05, Jul 07, Jul 14
6	Jun 29-Jul 21	17 (-6 to +17)	left	Jul 05	Jul 03-Jul 07, Jul 14
7	Aug 10-Sep 03	20 (-3 to +22)	left	Aug 13	Aug 22-Aug 26
8	Aug 10-Sep 07	29 (-7 to +22)	left	Aug 17	
9	Aug 10-Sep 07	28 (-5 to +22)	left	Aug 15	
10	Sep 25-Oct 22	28 (-1 to +27)	right	Sep 26	
11	Sep 25-Oct 22	28 (-4 to +24)	left	Sep 29	
12	Sep 25-Oct 22	28 (-1 to +27)	left	Sep 26	
13	Oct 22-Nov 13	17 (-1 to +16)	left	Oct 29	
14	Nov 02-Nov 14	13 (-7 to +6)	right	Nov 09	
15	Nov 02-Nov 30	19 (-6 to +23)	left	Nov 08	Nov 15-Nov 24



a b

Figure 1. Example of a) digital image and b) raw depth image of a lactating sow and litter in a farrowing crate.

2.2 Image processing principle and algorithm

The image-processing and analysis algorithm was developed using the MATLAB R2013b software. The processing results were saved to Mysql database. The algorithm identified the sow's behaviors based on the pre-processed depth image data. Lao et al. (2016) provides a detailed description of the algorithms used for the depth image processing and sow behaviors recognition. It should be clarified that the movement defined in this paper refers to that of the centroid of the sow's projected or horizontal image (between two consecutive images), not considering the vertical component. As such, the movement calculation equation is of the following form,

$$\text{Movement}=\sqrt{(x_{centroid1}-x_{centroid2})^2+(y_{centroid1}-y_{centroid2})^2}. \qquad (1)$$

$where\ centroid1\ and\ centroid2\ stand\ for\ the\ sow's\ centroid\ in\ the$ current and previous $image, respectively.$

3. Results and Discussion

3.1 Sow's lying behaviors

Table 2 to Table 4 summarize the percentages of the sows' different lying postures during P1, P2, P3 and P4. Data from 13 sows (excluding Sow 4 and Sow 6) were used to analyze the sow's lying patterns or preference during all except P3 periods in the farrowing cycle. For P3, all 15 sows were used. The reason for excluding the dataset of Sows 2 and 3 in the first analysis was due to the missing days of pre-farrowing and 3-day post parturition. The data (mean$\pm$SD) were analyzed to examine the lying behavioral changes over time and the impact of the heat lamp. Multiple pairwise t-test in SAS® was done on RS *vs.* LS, UTH *vs.* BTH with a period, and RS *vs.* RS, LS *vs.* LS, UTH *vs.* UTH, BTH *vs.* BTH between different periods. Differences were considered significant at $p<0.05$.

It can be seen from the date in Tables 2 to 4 that in P1 (before farrowing without HL), the sows did not show apparent preference of lying on one side over the other (52.8% RS *vs.* 47.2% LS, p=0.11). In P2 (before farrowing with HL), the sows did not show apparent preference of lying on UTH over BTH (51.5% UTH *vs.* 48.5% BTH, p=0.35).

In P3 (after farrowing with HL) a considerable change occurred in the sows' lying side in that they preferred to lie more in the BTH position than in the UTH position. This behavior continued for the entire P3, although the difference between UTH and BTH gradually decreased. The following provides a more detailed description.

In P3-1 (within 3 d of farrowing), the sows showed distinctive preference of lying on one side than the other: 43.3±3.2% (mean±SE) UTH *vs.* 56.7±3.2% BTH (p<0.05) (Table 3). The time spent by the sows in UTH posture (43.3±3.2%) in P3-1 was also significantly lower than the baseline value in P2 (51.5±2.2%) (p<0.05), up to 30% reduction in some cases. This outcome is quite surprising because it is not in the best interest of the piglets' well-being when they have to get milk from the sow on the "cool side" of the creep area, subjecting them to potential cold drafts and resultant health issues such as diarrhea. This is in contrast to the hypothesis that the sows would present her udders to the piglets more in the heated side. The higher percentage of lying in BTH *vs*. UTH might have resulted from the lactating sow's udders being more sensitive to the heat radiated from the lamp than her backside. This significant difference continued in P3-2 (within 6 d of farrowing) (44.9±2.4% UTH *vs.* 55.1±2.4% BTH, p<0.05). The difference in UTH between P3-2 and P2 was also nearly significant (p=0.057). In P3-3 (the last 3 days with HL after farrowing, which varied according to season), the sows gradually adapted to the heat lamp, although the time of UTH was still somewhat lower than BTH (48.8±3.0% *vs.* 51.2±3.0%).

Because approximately 50% of piglet pre-weaning death losses occur during the first 3 days of life, providing adequate microenvironment to the piglets during this period is particularly important. Getting a good start with the newborn piglets is also critically important to ensuring their health and production performance. Considering the sow's lying pattern of spending more time with her udders away from the heat source in the first few days of post-parturition, it might be prudent to provide the localized heat on both sides of the sow. Even if the sow spends her lying time equally on both sides, having the heat available on both sides should be conducive to ensuring well-being of the piglets. Nevertheless, the efficacy of such an arrangement on the health and performance of the piglets remains to be investigated. In addition, care should be taken to eliminate or reduce the unintended spread of the supplemental heat (radiative overhead or conductive floor heating) onto the sow.

In P4, with the heat lamp turned off, the sows began to return their lying pattern or habit toward the baseline level of pre-farrowing without HL (P1). However, by the end of the lactation period, the time of RS still tended to be lower than the time of LS (48.0% *vs.* 52.0 for P4 as compared to 52.8% *vs.* 47.2% for P1; p =0.53), implying that the less UTH (or RS) posture during the lactation period had some carryover effect on the sow's lying behavior. However, the current data did not allow for quantifying how long the carryover effect would last.

Table 2. Lying postures of sows in different farrowing periods (P1 = before farrowing without HL, P2= before farrowing with HL, P3= after farrowing with HL, P3-1= the first 3 days of P3, P3-2=the first 6 days of P3, P3-3=the last 3 days of P3, P4=after farrowing without HL)

Sow # / %		1	2	3	4	5	6	7	8	9	10*	11	12	13	14*	15	Mean	SE
P1	**RS**	x	x	x	49.4	58.4	50.7	58.1	40.0	59.4	x	x	x	x	55.1	51.2	52.8	2.3
	LS	x	x	x	50.6	41.6	49.3	41.9	60.0	40.6	x	x	x	x	44.9	48.8	47.2	
P2	**UTH**	59.6	x	x	44.1	x	x	59.1	42.6	50.3	63.7	55.7	52.3	50.4	47.6	41.1	51.5	2.2
	BTH	40.4	x	x	55.9	x	x	40.9	57.4	49.7	36.3	44.3	47.7	49.6	52.4	58.9	48.5	
P3	**UTH**	52.2	x	x	33.8	42.6	51.4	48.3	44.5	53.8	65.5	48.3	43.1	45.4	x	x	48.1	2.4
	BTH	47.8	x	x	66.2	57.4	48.6	51.7	55.5	46.2	34.5	51.7	56.9	54.6	x	x	51.9	
P3-1	**UTH**	36.4	x	x	37.8	x	x	54.8	50.7	49.6	54.2	44.9	21.7	29.0	49.9	47.1	43.3	3.2
	BTH	63.6	x	x	62.2	x	x	45.2	49.3	50.4	45.8	55.1	78.3	71.0	50.1	52.9	56.7	
P3-2	**UTH**	45.6	x	x	34.5	x	x	49.5	52.1	51.8	50.2	42.5	28.0	39.8	47.5	52.2	44.9	2.4
	BTH	54.4	x	x	65.5	x	x	50.5	47.9	48.2	49.8	57.5	72.0	60.2	52.5	47.8	55.1	
P3-3	**UTH**	44.0	57.1	45.7	44.9	38.0	37.5	49.6	40.5	51.7	79.1	53.0	49.0	44.7	x	x	48.8	3.0
	BTH	56.0	42.9	54.3	55.1	62.0	62.5	50.4	59.5	48.3	20.9	47.0	51.0	55.3	x	x	51.2	
P4	**RS**	63.8	x	x	x	38.9	53.3	49.7	48.1	66.2	20.2	57.0	48.3	x	x	34.5	48.0	4.4
	LS	36.2	x	x	x	61.1	46.7	50.3	51.9	33.8	79.8	43.0	51.7	x	x	65.5	52.0	

x =missing data. * Heat lamp was placed on the right side of the sow; whereas it was placed on the left side of the sow in all other crates.

Table 3. Comparison of sow's lying posture/side within each period (P1 = before farrowing without HL, P2= before farrowing with HL, P3= after farrowing with HL, P3-1= the first 3 days of P3, P3-2=the first 6 days of P3, P3-3=the last 3 days of P3, P4=after farrowing without HL, RS = lying on right side, LS = lying on left side, UTH = udders toward heat lamp, BTH = back toward heat lamp)

Variable	**P1**		**P2**		**P3**		**P3-1**		**P3-2**		**P3-3**		**P4**	
Lying	RS	LS	UTH	BTH	UTH	BTH	UTH	BTH	UTH	BTH	UTH	BTH	RS	LS
Mean	52.8	47.2	51.5	48.5	48.1	51.9	43.3	56.7	44.9	55.1	48.8	51.2	48.0	52.0
SE	2.3	2.3	2.2	2.2	2.4	2.4	3.2	3.2	2.4	2.4	3.0	3.0	4.4	4.4
p-value	0.106		0.354		0.275		**0.004**		**0.007**		0.585		0.527	

Table 4. Comparison of sow's lying posture/side between periods (P1 = before farrowing without HL, P2= before farrowing with HL, P3= after farrowing with HL, P4=after farrowing without HL, P3-1= the first 3 days of P3, P3-2=the first 6 days of P3, P3-3=the last 3 days of P3, P4=after farrowing without HL, RS = lying on right side, LS = lying on left side, UTH = udders toward heat lamp, BTH = back toward heat lamp)

Baseline Period – Lying Posture	**P3**		**P3-1**		**P3-2**		**P3-3**		**P4**	
	UTH	BTH	UTH	BTH	UTH	BTH	UTH	BTH	RS	LS
P1 – RS									0.383	
P1 – LS										0.383
P2 – UTH	0.312		**0.049**		**0.057**		0.495			
P2 – BTH		0.312		**0.049**		**0.057**		0.495		

3.2 Time budget of selected sow behaviors

The daily time spent in lying by the sows over the farrowing cycle was quantified. The time budget for lying, standing, sitting, and kneeling behaviors, along with cumulative movement were further assessed.

3.2.1 Percentages of lying, standing, sitting and kneeling beahviors

Daily distributions of the lying, standing, sitting and kneeling behaviors for 11 sows during the monitoring period (-3,-2,-1, 0, 1, 2, 3, 4, 5, 12, 19 days of the farrowing cycle were selected) are presented in Table 5. The percentage of lying posture decreased to the lowest on the day of farrowing (Mean±SE of 74.0±3.5%) and some on the day prior to farrowing (76.8±4.5%). Concurrently, the percentage of standing behavior rose to the highest (14.4±2.2% and 10.1±2.0%, respectively). The timing of the sow's farrowing determines the occurrence of the lowest lying percentage between the day before farrowing and the day of farrowing. The former corresponded to farrowing in the morning or earlier, whereas the latter corresponded to farrowing in the afternoon or evening. In either case, sow's lying posture dropped to the lowest point approximately 24 h prior to farrowing.

Figure 2 shows the temporal patterns of sows lying percentage relative to the total behaviors (lying, standing, sitting, and kneeling). The profiles confirm that 24 h prior to farrowing the sows show drastic decrease in their lying time. Afterwards the sows maintained relatively constant percentage of lying time.

Table 5. Sow's daily time distributions (%) of lying, standing, sitting and kneeling behaviors

Days of farrowing cycle	Sow #	3	4	7	8	9	10	11	12	13	14	15	Mean	SE
-3	**Lying**	x	86.2	90.2	86.8	91.4	x	77.9	x	x	77.9	88.2	85.5	2.1
	Standing	x	6.6	6.1	4.1	5.6	x	8.2	x	x	6	5.9	6.1	0.5
	Sitting	x	6.9	3.5	9.0	2.4	x	13.3	x	x	13	5.7	7.7	1.6
	Kneeling	x	0.3	0.2	0.1	0.2	x	0.6	x	x	3.2	0.2	0.7	0.4
-2	**Lying**	x	86.8	89.0	83.4	89.6	x	72.5	x	x	80.4	84.9	83.8	2.2
	Standing	x	3.6	6.0	7.2	6.7	x	7	x	x	7.3	8	6.5	0.5
	Sitting	x	9.4	4.7	9.2	3.4	x	18	x	x	10.9	6.9	8.9	1.8
	Kneeling	x	0.2	0.3	0.1	0.2	x	2.5	x	x	1.4	0.2	0.7	0.3
-1	**Lying**	x	77.4	75.5	70.6	81.6	95.6	47	95.5	78.6	80.8	65.8	76.8	4.5
	Standing	x	14.9	11.4	11.5	8.9	0.4	15.3	1.4	8.6	6.9	21.8	10.1	2.0
	Sitting	x	7.2	12.4	17.6	7.2	3.8	26.1	2.8	12.4	10.4	11.8	11.2	2.2
	Kneeling	x	0.5	0.7	0.3	0.3	0.2	11.6	0.3	0.4	1.9	0.7	1.7	1.1
0	**Lying**	x	89.9	76.2	65.2	69.4	57.4	92	74.7	72.6	63.2	79.6	74.0	3.5
	Standing	x	6.9	10.2	18	23.8	22.4	1.3	15.9	16.3	17.6	11.5	14.4	2.2
	Sitting	x	2.9	13.1	16.3	6.2	17.6	5.9	8.3	10	16.9	8.3	10.6	1.6
	Kneeling	x	0.3	0.5	0.5	0.6	2.6	0.8	1	1.2	2.4	0.6	1.1	0.3
1	**Lying**	x	90.8	90.4	89.9	96.9	93.6	91.8	92.5	90.8	91.8	88	91.7	0.8
	Standing	x	7.1	6.3	5.4	2.6	2.9	5.9	6.3	6.6	4.2	9.2	5.7	0.6
	Sitting	x	2	3.2	4.6	0.4	3.5	2.1	1	2.5	3.6	2.8	2.6	0.4
	Kneeling	x	0	0.1	0.1	0	0	0.2	0.2	0.1	0.3	0.1	0.1	0.0
2	**Lying**	x	88.7	87.3	83.3	96	92.1	91.1	92	82.2	89.2	85.1	88.7	1.4
	Standing	x	8.2	9.8	9	3.7	5.7	6.1	6.7	13	5.9	11.2	7.9	0.9
	Sitting	x	3	2.9	7.6	0.2	2.2	2.8	1.2	4.7	4.4	3.6	3.3	0.6
	Kneeling	x	0.1	0.1	0.1	0	0	0.1	0.1	0.1	0.4	0	0.1	0.0
3	**Lying**	84.8	87.5	91.8	88.6	94.5	83.1	86.6	90.4	91.9	91.1	89.8	89.1	1.0
	Standing	9	7.8	6.8	6.1	4.7	10.2	5.9	8.8	6.2	5.1	7.6	7.1	0.5
	Sitting	6.1	4.6	1.4	5.2	0.5	6.6	7.3	0.7	1.9	3.6	2.5	3.7	0.7
	Kneeling	0.1	0.1	0	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.0
4	**Lying**	86.2	85	89.3	89.4	94.9	86.3	88.6	91.2	89.6	87.7	91.6	89.1	0.8
	Standing	9.5	8.9	9.2	4.2	4.6	8.7	6.8	7.2	7.6	5.6	6.1	7.1	0.5
	Sitting	4.1	6	1.5	6.3	0.5	4.9	4.4	1.5	2.7	6.3	2.2	3.7	0.6
	Kneeling	0.1	0.1	0	0.1	0	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.0
5	**Lying**	86.2	86.6	87.3	89.8	93.4	84.6	82.8	91	90.5	x	86.1	87.8	1.0
	Standing	9.5	8.9	11.5	4.5	5.3	10	7.3	7.9	7.4	x	8.7	8.1	0.7
	Sitting	4.1	4.4	1.1	5.6	0.9	5.3	9.6	0.9	2.1	x	5.1	3.9	0.9
	Kneeling	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	x	0.1	0.1	0.0
12	**Lying**	87.6	x	87.5	86	92.1	87.6	86.7	91.4	86.5	x	x	88.2	0.8
	Standing	9.1	x	11.5	8.9	7.1	6.6	9.9	6.6	11	x	x	8.8	0.7
	Sitting	3.2	x	0.9	5	0.7	5.7	3.3	1.9	2.4	x	x	2.9	0.6
	Kneeling	0.1	x	0.1	0.1	0.1	0.1	0.2	0.1	0.1	x	x	0.1	0.0
19	**Lying**	84.4	x	89.5	86	92.1	82.9	84.3	87.7	x	x	84.5	86.4	1.1
	Standing	12.4	x	9.7	9.2	6.3	10.6	11.9	10	x	x	12.4	10.3	0.7
	Sitting	3.2	x	0.7	4.8	1.1	6.3	3.6	2	x	x	2.9	3.1	0.7
	Kneeling	0.1	x	0.1	0.1	0.2	0.3	0.2	0.2	x	x	0.2	0.2	0.0

x = missing data. Note that the day used in this table covers the hours of midnight to midnight, also referred to as natural day.

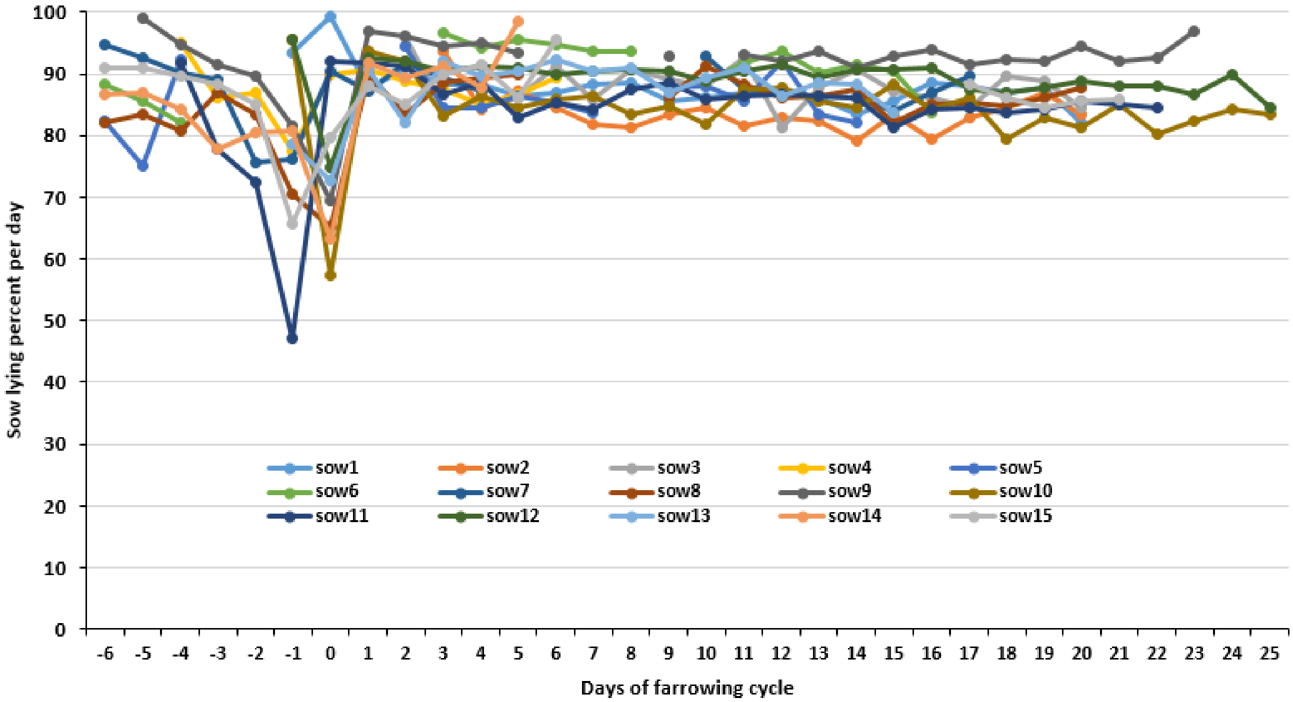


Figure 2. Sow's daily percent time of lying during pre- and post-farrowing.

Differing from the natural day (midnight to midnight) used in Table 5, the exact hours from the time of the sow's farrowing was determined and are summarized in Table 6. It can be seen that the behavioral distributions for the 24 h prior to farrowing (mean±SE) were 64.6±2.4% in lying, 19.9±1.4% in standing, 14.0±1.9% in sitting, and 1.5±0.4% in kneeling, as compared to 80.2±2.4% (lying), 9.2±1.0% (standing), 10.1±1.7% (sitting), and 0.5±0.1% (kneeling) over the 24~48 h before farrowing. The 24 h prior behavioral distributions were also compared to 86.1±1.5% (lying), 6.4±0.6% (standing), 7.1±1.2% (sitting), and 0.4±0.1% (kneeling) over the 48~72 h before farrowing, and to 88.1±0.8% (lying), 8.2±0.6% (standing), 3.4±0.6% (sitting), and 0.3±0.1% (kneeling) over all monitoring time (except for the 24 h prior to farrowing). The much reduced lying time but increased standing time in the 24 h prior to farrowing is indicative of a strong nest-building behavior of the sows. The overall behavioral values (86.6% lying, 4.4% sitting, 8.7% standing and 0.3% kneeling) paralleled the literature report that sows spend 85%-90% of their time lying down, 4.8% sitting time, 5.8% standing, and 0.1% kneeling (Whittaker et al., 1999; Johnson et al., 2001; Velarde and Geers, 2007; Rolandsdotter et al., 2009; Beirendonck et al., 2014). Sow 14 consistently showed higher kneeling percentages than other sows, although the reasons were unknown.

Table 6. Partitioning of sow behaviors during different periods of the farrowing cycle (%)

Sow#	24 h prior to farrowing				24~48 h prior to farrowing				48~72 h prior to farrowing				All farrowing time (except for 24 h prior to farrowing)				All farrowing time (include 24 h prior to farrowing)			
	L	St	Si	K	L	St	Si	K	L	St	Si	K	L	St	Si	K	L	St	Si	K
3	65.4	27.4	6.7	0.5	x	x	x	x	X	x	x	x	87.3	9.3	3.3	0.1	86.3	9.9	3.6	0.1
4	76.5	15.0	7.8	0.7	87.2	6.9	5.8	0.2	90.3	2.5	7.0	0.2	88.4	6.8	4.7	0.1	87.6	7.3	5.0	0.2
7	63.9	14.5	20.7	0.9	84.8	7.8	7.0	0.4	90.7	5.5	3.6	0.2	89.1	8.7	2.1	0.1	87.6	9.2	3	0.2
8	61.9	18.3	19.4	0.5	74.1	10.5	15.1	0.2	84.8	7.1	7.9	0.1	85.5	7.6	6.7	0.1	84.6	8.1	7.2	0.1
9	64.4	25.9	9.0	0.6	87.1	8.2	4.5	0.2	89.3	6.9	3.6	0.2	93.1	5.6	1.1	0.1	92.1	6.1	1.4	0.2
10	57.6	22.3	17.5	2.5	x	x	x	x	X	x	x	x	84.9	8.4	6.5	0.2	83.9	8.9	6.9	0.3
11	47.6	22.6	25.3	4.5	69.7	14.7	15.0	0.6	79.8	7.3	12.5	0.4	85.0	12.1	2.7	0.2	83.6	12.6	3.4	0.3
12	74.4	15.8	8.7	1.0	x	x	x	x	x	x	x	x	89.5	8.5	1.8	0.2	88.9	8.7	2.1	0.2
13	70.9	17.0	10.9	1.2	73.3	10.5	15.4	0.4	85.9	8.6	4.8	0.7	87.4	9.0	3.4	0.2	87.3	9.1	3.5	0.2
14	62.9	17.6	16.4	3.2	80.8	6.5	11.2	1.5	80.6	6.8	11.4	1.2	92.4	5.4	0.8	1.4	84.2	6.1	8.4	1.4
15	65.2	22.5	11.5	0.8	84.7	8.4	6.7	0.2	87.8	6.1	5.9	0.2	87.2	8.8	3.9	0.1	86.5	9.2	4.2	0.2
Mean	64.6	19.9	14.0	1.5	80.2	9.2	10.1	0.5	86.1	6.4	7.1	0.4	88.1	8.2	3.4	0.3	86.6	8.7	4.4	0.3
SE	2.4	1.4	1.9	0.4	2.4	1.0	1.7	0.1	1.5	0.6	1.2	0.1	0.8	0.6	0.6	0.1	0.8	0.5	0.7	0.1

L = Lying, St = Standing, Si = Sitting, K = Kneeling, x = missing data.

3.2.3 Daily movement profiles of the sow

Daily movement of individual sows in the horizontal plane and the overall mean (±SE) are presented in Figure 3 (-3,-2,-1, 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 17, 19 days of the farrowing cycle were selected). It is clear that the sows displayed a considerable increase in daily movement the day before or on the day of farrowing, which was consistent with the reduced lying and increased standing for the same period. It can also be seen that the daily movement gradually increased during the lactation period. This outcome presumably resulted from the sow's increased feeding activities to meet the increasing milk demand by the growing piglets.

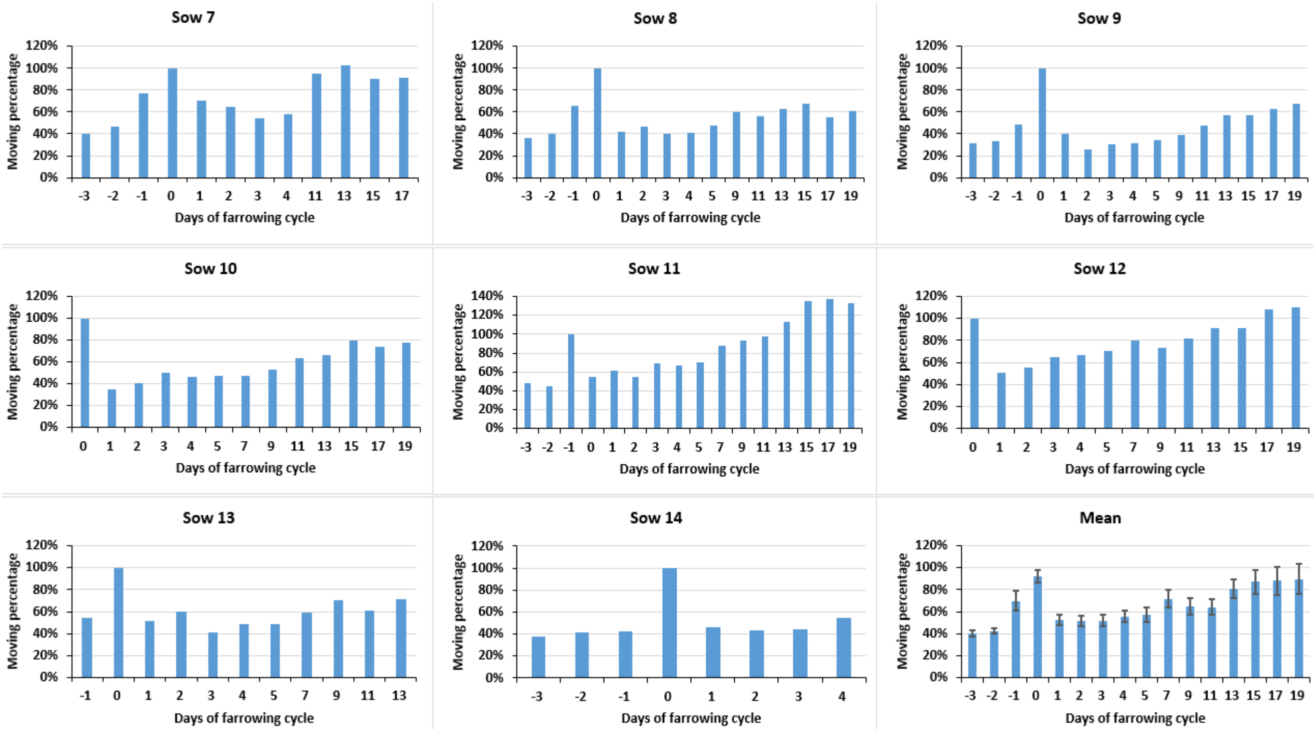


Figure 3. Examples of a sow's daily movement throughout the farrowing cycle.

The results indicate that by automatically tracking the changes in lying, standing, or daily movement of the gestating sow near farrowing time, the system can predict the timing of farrowing. Such a tool will prove useful to the farrowing management, thus conducive to ensuring a good, healthy start of the newborn piglets.

Preliminary Conclusions

Depth images of sows in farrowing crates were acquired with low-cost Kinect camera and analyzed to quantify postural and dynamic behaviors before, during and after farrowing. The primary objective was to determine if sows have any preference of lying on one side *vs.* on the other, and how such a pattern would be affected by the presence of a heat lamp on her side (i.e., in the creep area) – udders toward the heat lamp (UTH) *vs.* backside toward the heat lamp (BTH). Data with 15 sows thus far reveal the following preliminary observations. More data collection and analysis is continuing to strengthen the findings.

- The sows did not seem to have a strong preference to lie on one side more than the other before farrowing regardless of lack or presence of a heat lamp on the side.
- The heat lamp in the creep area affected the sow's lying side in the first 3 days after farrowing in that the time of UTH significantly reduced ($p<0.05$).
- The presence of heat lamp during the lactation period seemed to have a carryover effect on the lying posture of the sow after the heat lamp has been turned off with elder piglets.
- Sows change their lying, sitting, standing, and movement behaviors over the farrowing cycle. In particular, sows change these behaviors distinctively 24 h prior to farrowing or on the farrowing day, making it possible to determine the farrowing time by analyzing the behavioral changes such as used in the current system.

Acknowledgements

This study was funded in part by the project of "Twelfth Five-Year-Plan" in National Science and Technology for the Rural Development in China (2014BAD08B05-01), the College of Agriculture and Life Sciences at Iowa State University, and USDA-ARS Meat Animal Research Center. Special thanks go to the staff of the USDA Meat Animal Research Center for their assistance in data collection and animal care.

References

Alonso, S.M., Ramirez, N.R., Gonzalez, L.M., Mota, R.D., Trujillo, O.M.E. (2007). Piglet survival in early lactation: a review. Journal of Animal and Veterinary Advances, 6(1): 76-86.

Baxter, E.M., Jarvis, S., Sherwood, L., Farish, M., Roehe, R., Lawrence, A.B., Edwards, S.A. (2010). Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. Applied Animal Behaviour Science, 130(2011): 28-41.

Beirendonck, S.V., Thielen, J.V., Verbeke, G., Driessen, B. (2014). The association between sow and piglet behavior. Journal of Veterinary Behavior, 9:107-113.

Cornou, C., Kristensen, A. (2014). Monitoring individual activity before, during and after parturition using sensors for sows with and without straw amendment. Livestock Science. 168:139–148.

Cornou, C., Lundbye-Christensen, S. (2010). Classification of sows' activity types from acceleration patterns using univariate and multivariate models. Computers and Electronics in Agriculture. 72(2), 53–60.

Escalante, H.J., Rodriguez, S.V., Cordero, J., Kristensen, A.R., Cornou, C. (2013). Sow-activity classification from acceleration patterns: A machine learning approach. Computers and Electronics in Agriculture, 93:17–26.

Gregersen, T., Jensen, T., Andersen, M., Mortensen, L., Maselyne, J., Hessel, E., Ahrendt, P. (2013). Consumer grade range cameras for monitoring pig feeding behaviour. In: 6th European Conference on Precision Livestock Farming, 2013 (pp. 360–369). Leuven, Belgium.

Johnson, A.K., Morrow-Tesch, J.L., & McGlone, J.J. (2001). Behavior and performance of lactating sows and piglets. Journal of Animal Science, 79: 2571-2579.

Lao, F., Stinn, J.P., Xin, H., Brown-Brandl, T., Liu, K. (2015). Determination of piglet location in farrowing crates based on depth and digital images. In Proc. Precision Livestock Farming'15 (pp. 563-572). Milan, Italy.

Lao, F. T.M. Brown-Brandl, J.P. Stinn, K. Liu, G. Teng, and H. Xin. (2016). Automatic recognition of lactating sow behaviors through depth image processing. Computers and Electronics in Agriculture 125:56-62. http://dx.doi.org/10.1016/j.compag.2016.04.026

Oczak, M., Maschat, K., Berckmans, D., Vranken, E., Baumgartner, J. (2015). Classification of nest-building behaviour in non-crated farrowing sows on the basis of accelerometer data. Biosystems Engineering, 140:48–58.

Rolandsdotter, E., Westin, R. & Algers, B. (2009). Maximum lying bout duration affects the occurrence of shoulder lesions in sows. Acta Veterinaria Scandinavica, 51(44):1–7.

Shankar, B.P., Madhusudhan, H.S., & Harish, D.B. (2009). Pre-weaning mortality in pig-causes and management. Veterinary World, 2(6):236-239.

Van Hertem, T., Maltz, E., Antler, A., Alchanatis, V., Schlageter-Tello, A., Lokhorst, C., Romanini, C.E.B., Viazzi, S., Bahr, C., Berckmans, D., Halachmi, I. (2013). Automatic lameness detection based on 3D-video recordings. In: 6th European Conference on Precision Livestock Farming, 2013 (pp. 59–67). Leuven, Belgium.

Velarde, A. & Geers, R. (2007). On farm monitoring of pig welfare, (pp. 19–23). Wageningen Academic Publisher, Wageningen.

Viazzi, S., Ismayilova, G., Oczak, M., Sonoda, L.T., Fels, M., Guarino, M., Vranken, E., Hartung, J., Bahr, C., Berckmans, D. (2014). Image feature extraction for classification of aggressive interactions among pigs. Computers and Electronics in Agriculture, 104:57–62.

Viazzi, S., Van Hertem, T., Romanini, C.E.B., Bahr, C., Halachmi, I., Schlageter Tello, A., Lokhorst, C., Rozen, D., Berckmans, D. (2013). Automatic back posture evaluation in dairy cows using a 3D camera. In: 6th European Conference on Precision Livestock Farming, 2013 (pp. 83–91). Leuven, Belgium.

Xin, H., Zhou, H., and Bundy, D.S. (1997). Comparison of energy use and piglet performance between the conventional and an energy-efficient heat lamp. Applied Engineering in Agriculture, 13(1): 95-99.

Zhang, Q. and Xin, H. (2000). Modeling of heat mat operation for piglet creep heating. Transactions of the ASAE 43(5): 1261-1267.

Zhang, Q. and Xin, H. (2001). Responses of piglets to creep heat type and location in farrowing crate. Applied Engineering in Agriculture 17(4): 515-519.

Zhang, Q. and Xin, H. (2005). Resting behavior of piglets in farrowing crates equipped with heat mats. Applied Engineering in Agriculture 21(6): 1067-1071.

Zhou, H. and Xin, H. 1999. Effects of heat lamp output and color on piglets at cool and warm environments. Applied Engineering in Agriculture 15(4): 327-330.